Application of Printing Telegraph to Long-Wave Radio Circuits *

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This paper describes certain arrangements which have been used for start-stop printing telegraph operation over a transatlantic long-wave radio channel and also describes results obtained from certain tests of long-wave teletypewriter transmission from Rocky Point, L. I., to Rochester, N. Y. A prediction of year-round results is obtainable by correlation of these test data with year-round noise measurement data taken at Houlton, Maine, in connection with transatlantic telephone service.

PRINTING telegraph equipment,[1] because of its speed, accuracy and convenience in transmitting intelligence, has become recognized as a very useful method of telegraphy on wire circuits. It seems important, therefore, to determine something of the possible utility of present types of teletypewriters on radio circuits.

It is common practice to transmit the signals for operating teletypewriter equipment over wire circuits in any one of several electrical forms. As in earlier telegraph practice the signals are frequently transmitted as d-c impulses. More recently alternating currents of voice-frequency and of higher frequency have been employed.[2] In employing radio frequencies for operating teletypewriter equipment where the operating impulses are no longer guided by a wire circuit, new problems and new conditions arise, which are essentially those of radio telegraph transmission. For this reason, it is desirable to review briefly the conditions under which radio telegraph systems are operated.

In manual-sending aural-receiving practice for radio telegraphy it has been customary to utilize, at the receiving end, only a marking tone or sound which is received during intervals corresponding to the time that the sending key is depressed. In transmitting signals from an arc transmitter, a signal of a different frequency is sent out during the spacing periods in order to simplify the keying process, but this spacing signal is not utilized at the receiving end. For aural reception the necessary and sufficient requirement is that the marking tone be distinguishable through the noise. Using ear receiving it is possible to distinguish the signal under a wide variation of conditions because of the ability of the ear to accomodate itself to variations in signal level and in signal-to-noise ratio.

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From the transmission standpoint, tape or automatic sending, i.e., sending from a tape perforated in accordance with a telegraphic code, is merely a matter of increasing speed and accuracy of the characters transmitted.[3] Automatic tape recording of radio signals, such as by the syphon recorder or similar device, removes the advantage obtained from the tone character of the signal, so useful in ear reception, and substitutes for this tonal character the less acute ability of the eye to distinguish between signals and noise on the tape record.[4] In sacrificing this ability to receive with greater accuracy in the presence of considerable noise there is, however, a gain in the speed of receiving radio signals. The tape record, which is in permanent form, makes it possible for several operators simultaneously to transcribe different parts of the received message at speeds much slower than the transmitting speed.

Printing telegraphy goes one step further in removing the human element from the process of receiving and substituting a mechanism which must be impelled to a definite act by each current element received. The printing mechanism inevitably records what it receives without using any judgment factor in the process other than the mechanical application of such fixed criteria as have been put into it by the designer. Unless the transmitted signal is received with such intensity and character as to be the controlling signal at the receiving end, errors will usually result. The use of printing telegraph equipment on radio circuits,[5] therefore, makes the signal-to-noise ratio necessary for the receiving of satisfactory copy greater than would be required for either aural reception or tape signal recording.

It is of considerable interest to compare the approximate minimum values of signal-to-noise ratio required for satisfactory * transmission of intelligence by single side band long-wave radio using the customary double side band carrier telegraph. This has been done in the table on the following page.

When automatic means for recording the signals are applied at the receiving end of a radio circuit it is desirable that considerable uniformity exist in the output level of the receiving equipment. This is even more important when printing equipment is used. Such a condi-

* Obviously, "satisfactory" cannot have a definite quantitative meaning which is applicable to all modes of communication under all variations in the observed types of received noise. For example, "crashy static" would probably not be as serious in receiving by ear as it would be in receiving by other means. Then too, there is the personal judgment factor in determining just what constitutes "satisfactory" communicaton. The table is set up on a relative basis using quantitative values of signal-to-noise ratio which appear to represent the worst condition under which communication could be effected with only an occasional error. Of course, communication can be continued under much worse conditions, but with an increase in the number of errors.

TABLE I

Type of Facility	Speed of Transmission (Words per Minute)	Approximate Radio Band Width Occupied (Cycles per Second)	Approximate Minimum Signal-to-Noise Ratio for Satisfactory Communication ($20 \log_{10} S/N$)**
Manual-sending, aural-receiving. cw	20	35	10
Manual-sending, aural-receiving. cw	30	50	15
Automatic-sending tape-recording. cw	80	140	20
Single-tone printer system	60	110	30
Two-tone printer system.	60	220	30
Single side band telephony	200	2700	40***

** N is assumed to be measured in a constant band width of about 2200 cycles using the "warbler method"[6] of noise measurement.
*** S is assumed to be about 5 db above 1 milliwatt where speech is at reference volume.

tion is rather to be expected inasmuch as ultimately in the system there must be a relay mechanism operated by the signals. This relay must with a certain degree of accuracy reproduce the length of the signal impulse. It is desirable to have the relay remain unbiased over a considerable range of variation in signal level. If a signal impulse is transmitted only for marking, the spacing signal becomes an interval of no current and the restoring force on the relay must be applied locally by either electrical or mechanical means. Then with signals of the usual rounded wave shape, if the relay operating force varies while the restoring force remains constant, the signals are either "heavy" or "light," that is, the marking intervals are either lengthened or shortened and the system becomes biased.[7] *

The most obvious way of avoiding these difficulties is some arrangement in which the restoring force on the relay is varied in a manner similar to the operating force resulting from the received signal. One method of accomplishing this result which has been found quite effective is the two-tone method of transmission. As far as the radio circuit is concerned the signals consist of a marking and a spacing signal transmitted on slightly different frequencies. Since these two signals traverse the same transmission medium, they are, at least when there is no selective fading, subjected to similar variations in the equivalent of the transmission path. Therefore, if a polar receiving relay is operated by using one of these frequencies to produce the operating force and the other frequency to produce the restoring force, no bias results. The increase in magnitude of variations of the transmission

* Details are given on this effect and methods for its measurement in reference 7.

circuit which can be tolerated by employing this two-tone method of transmission instead of the single-tone method with a fixed bias is shown by Fig. 1.

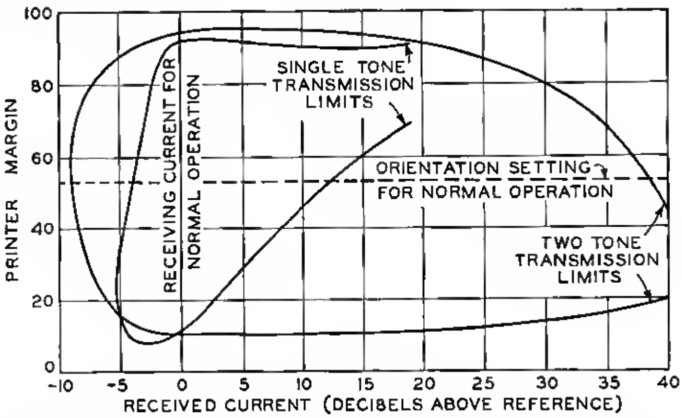

Fig. 1—Relation between received current and printer operating margin for the two-tone and single interrupted tone methods of signaling.

These curves show the relation between operating current and the limits of printer margin [7] within which correct operation is secured for both the single interrupted tone method of signaling and for the two-tone method. The upper and lower limits of the printer margin are shown to meet at the lower levels of received current, indicating that the printer fails completely at these levels. As might be expected, increasing the received current level a few db does not affect the orientation range as seriously as a corresponding decrease. In each condition, however, the margin is less affected when signaling by the two-tone method. Were it not for the presence of noise on the radio circuit, it would be possible to establish the normal operating current at a higher value. The reason why this is not feasible is that the detectors in the voice-frequency telegraph receiving equipment are operated near the upper bend of their characteristics. Under this condition increasing the gain causes a relatively small increase in current from the rectifier that is receiving both noise and signal inputs while the current from the rectifier that is receiving noise only is increased.

Thus because of the desirability of operating through high noise levels on long-wave radio circuits, it is not advantageous to utilize all of the available protection against signal level changes. Rather, a compromise is sought which will afford satisfactory protection against reasonable signal level variations without making the receiving equipment unduly vulnerable to noise. This practical operating point has

been selected at the zero indicated on this figure. The tolerance in received current level variations usually obtained is about ± 3 db in the case of single-tone signaling as compared to about ± 7 db for two-tone signaling. On the transatlantic long-wave radio circuits variations greater than those tolerated by the two-tone transmission method seldom occur with sufficient rapidity to escape manual correction.

With the two-tone system the amount of noise entering the receiving mechanism comes in through double the band width used in the single-tone system,[8] and the intelligence transmitted is completely contained in both the marking and the spacing signals. It is, therefore, logical to expect that there will not be much difference between the two-tone and single-tone systems from the noise interference standpoint. If there were no received signal the noise through the marking and spacing filters probably would balance out to some extent but during operation either the mark or space signal is always present. The noise may effectively annul either signal by being approximately of equal intensity and opposite phase, but the noise through the other filter is received with the full intensity and, therefore, may operate the relay falsely.

Employing printing telegraph equipment on radio circuits is not new.[5,9,10,11] There has, however, been comparatively little commercial use of such systems and there have been very few quantitative data published. Such practical information and quantitative data as have heen obtained by the Bell System regarding the application of printing telegraph to radio circuits relate to long-distance overseas point-to-point communication and a short-distance point-to-point overland circuit. Both of these circuits were operated on long waves (about 60 kilocycles).

For the past three years printing telegraph has been employed on the long-wave radio telephone circuit [12] between New York and London to exchange information pertaining to the operation of this telephone service. The printer is admirably suited to this kind of service since the information exchanged frequently consists of foreign names of places and people not familiar to the switchboard operators. By the use of the printer, these can be spelled out with speed and accuracy without the necessity of attempted pronunciation.

The printing telegraph arrangements provided at New York for use of the telephone traffic department on the transatlantic circuits are shown in Fig. 2. The instruments are installed on the table in the foreground. This table is located just behind the switchboard operators. As a large majority of the business transacted is of a question and answer nature, there are special arrangements in the printer to

indicate whether the message printed originated with the New York or with the London operator. Messages transmitted from the local machine are typed in red while those received from the distant terminal are typed in black. This was accomplished by modifying the mechanism of the machine to automatically shift a half red and half black typing ribbon.

Fig. 2—Transatlantic telephone operator's position showing arrangement of printing telegraph equipment.

The voice-frequency telegraph terminal equipment [2] and its associated apparatus are shown in Fig. 3. The equipment comprises the voice-frequency terminal set for repeating between the local d-c printer loop circuit and the a-c line circuit. The printer switching circuits, testing arrangements, and monitoring equipment are, for convenience, included in the same assembly of apparatus. The installation includes all the equipment necessary for one channel of a two-tone carrier tele-

graph system and sufficient equipment for adding another by providing suitable filters and a small amount of additional apparatus.

The connection of the printers to the telephone circuit is shown schematically in Fig. 4. The transmitting telegraph circuits are not

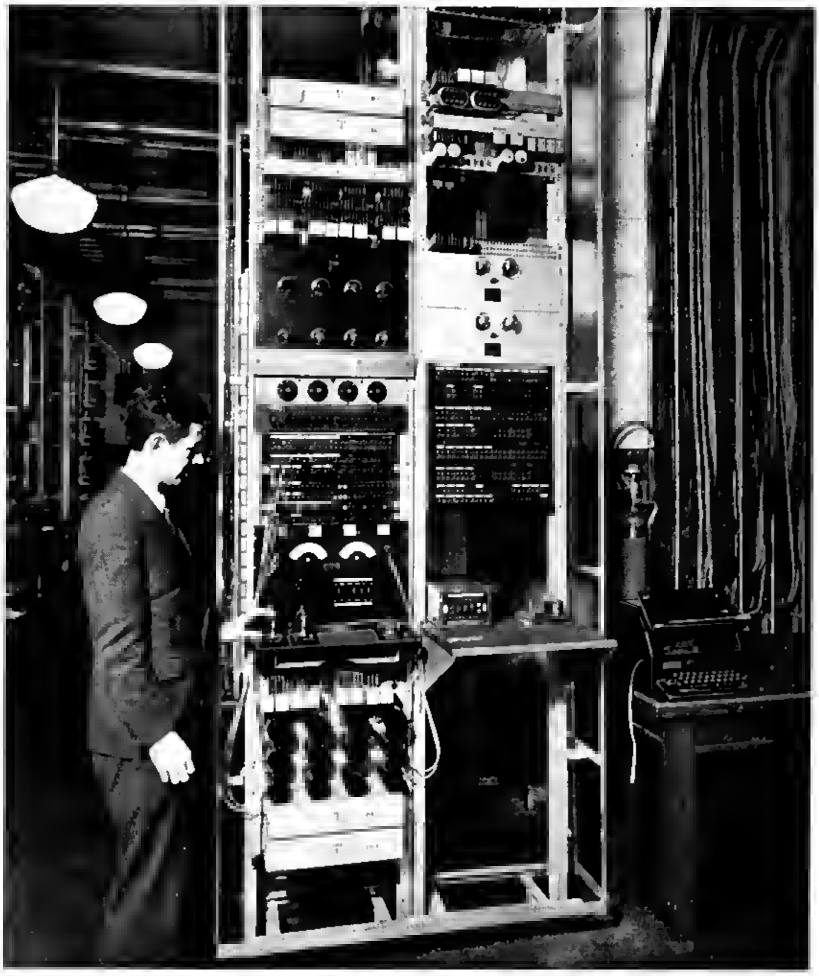

Fig. 3—Equipment for use in applying printing telegraph signals to the transatlantic radio telephone circuit at the technical operator's position.

connected permanently to the radio channel. When it is desired to establish the telegraph circuit, the connection is made through the operator's cord circuits into the transatlantic two-wire telephone circuit in a manner similar to that used to connect telephone subscribers. Audible

monitoring arrangements are provided for the telephone operator, the technical operator, and the printer operator. The distant terminal operator may interrupt the printer circuit with voice if such interruption seems expedient. In addition to the printer used by the printer operator, a printer at the technical operator's position, not shown in Fig. 4, is continuously connected to monitor on the system.

It should be noted that in the arrangement shown in Fig. 4 two different voice frequencies are used for transmission and two others for reception, thus giving the advantages of the two-tone method of transmission. The voice-frequency tones go out over wire circuits to the transmitting station at Rocky Point where, by means of the single side band suppressed-carrier method of radio transmission [13,14] shown in Fig. 4, they are changed to radio frequencies of about 60 kilocycles and amplified. The equivalent radiated power for each frequency is about 50 kilowatts. For signals coming from England much the same process is followed at the British end, the radiated frequencies, however, being different from those transmitted in the opposite direction.

The most serious handicap in the use of printing telegraph on the long-wave channel is noise. During the winter months little trouble is experienced, but interruptions are frequent and are occasionally of several hours' duration during the summer months. At the radio receiving stations the directive antenna systems used for telephony [15] greatly reduce the noise received.

Another important factor in reducing receiving interference is the frequency selectivity. The radio receiver itself restricts the received band sharply to that required for single side band telephony, passing a band about 3000 cycles wide. This is accomplished by the single side band carrier resupplied receiver [14] shown in Fig. 4. The band admitted to each of the tone channel detectors beyond the receiver is narrowed down to about 110 cycles by a voice-frequency filter as indicated in Fig. 4. It is estimated that if the printer were used continuously on the long-wave transatlantic channel for the entire year, the per cent of errors would exceed 0.1 per cent less than 12 per cent of the time and 5.0 per cent less than 2 per cent of the time.

In order to obtain more accurate quantitative information regarding the effect of noise on the transmission of teletypewriter signals over radio circuits, a series of tests was carried out during 1930. For the purpose of these tests a radio circuit was established between the transmitting station at Rocky Point, L. I., and a temporary receiving station at Rochester N. Y., a distance of 286 miles.

This one-way circuit utilized at New York the transatlantic transmitting facilities for printing telegraph described above with the ex-

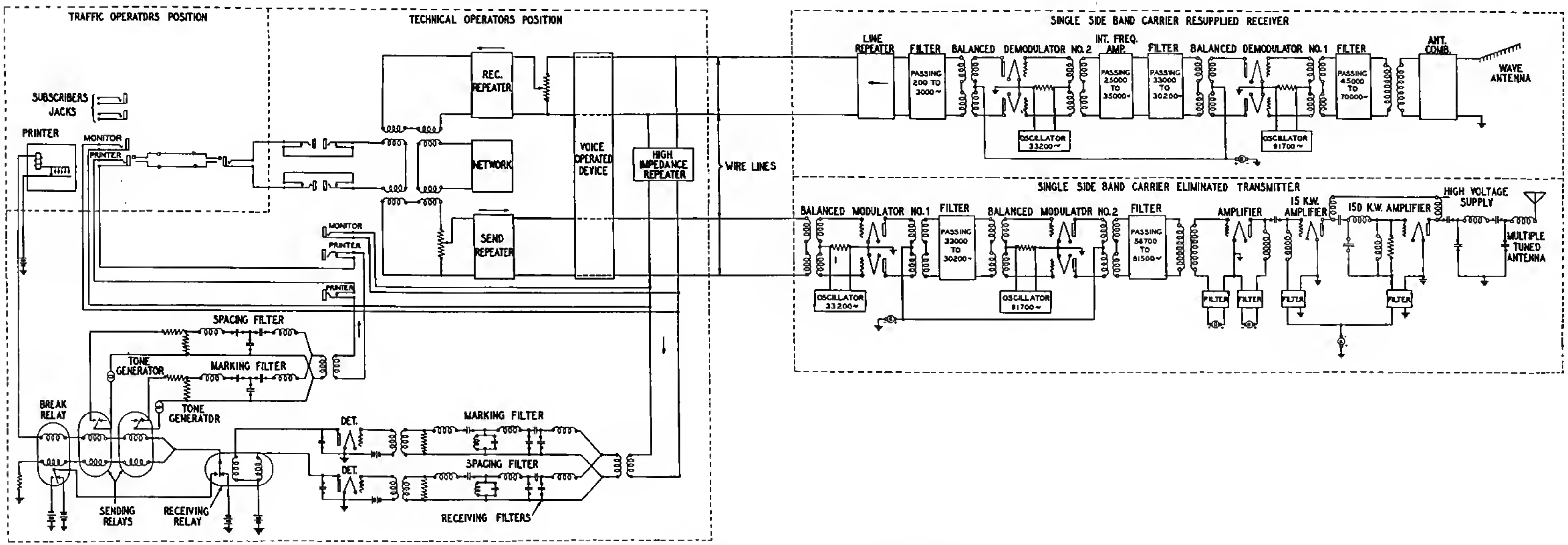

Fig. 4—Schematic of printer connection to transatlantic radio telephone circuit.

ception that automatic transmission from a perforated tape for operating page teletypewriters was substituted for the manual keyboard method for operating tape printers ordinarily used.

At Rocky Point the power of the radio transmitter was greatly reduced for these tests. The average power radiated in the direction of Rochester was equivalent to 0.7 kilowatt radiated from a nondirectional antenna. The average deviation from this value was less than 1 db. Under these conditions the average field received in Rochester was 42.5 db above one microvolt per meter. The average deviation from this mean value was less than 2 db. A daily half-hour test was made in the afternoon or evening at a time so chosen as to avoid the sunset period of disturbed radio transmission.

At Rochester, laboratory type receiving equipment was employed for picking up the radio signals and demodulating them to voice frequencies. The voice-frequency signals were then used to operate standard voice-frequency carrier terminal equipment at Rochester. This was modified for two-tone operation in a manner similar to that shown for the transatlantic receiving terminal in Fig. 4.

The teletypewriter signals were sent out from New York at 60 words per minute from an automatic tape transmitter. The copy received over the radio circuit was subsequently compared with simultaneously recorded copy which was not sent over the radio circuit. Keyboard errors which occur occasionally in perforating the tape for automatic transmission appeared on both copies. Disregarding these errors and counting all which did not appear on both copies, it was possible to obtain the per cent of errors caused by radio transmission. During the half-hour daily test period, about 10,000 characters were sent. It is apparent that rates of error which were less than about 0.1 per cent could not be determined accurately.

Before making the half-hour test each day to determine the per cent of errors received at Rochester, measurements were made of the amount of signal and of noise in the output of each voice-frequency filter. The signal-to-noise ratio thus measured was assumed to be the value obtaining over the succeeding half hour of test. The nature of these measurements was such that the data were somewhat scattered. However, by suitable smoothing procedures the approximate curve shown in Fig. 5 was plotted.

At Houlton, Maine, routine radio noise [6] observations are made four times each day on a loop antenna and hourly on the wave-antenna system, as a part of the operating procedure in maintaining transatlantic telephone service.[15] It seemed desirable to find out whether these data which extend over several years could be utilized to extrapolate

the Rochester data into other months. An examination of the noise data observed on the loop antenna at Houlton along with the loop antenna received noise obtained at Rochester, New York, point by point during the period of these tests indicated a fairly constant difference between the noise at these two places. On 37 days during September, October and November 1930, observations of printer operation at Rochester and noise observations at Houlton were made within the same hour. Using the errors observed in the Rochester radio copy on these 37 days and the corresponding 37 values of loop noise at Houlton the cumulative curves shown in Fig. 6 were obtained. From these two curves the same relation as shown in Fig. 5 can again be obtained.*

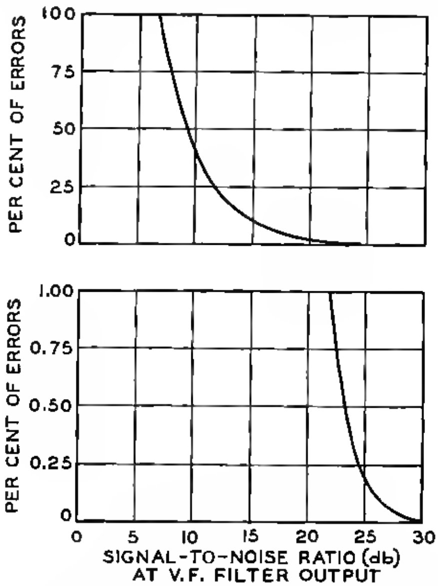

Fig. 5—Relation between printer errors and signal-to-noise ratio as determined from the Rocky Point-to-Rochester tests.

Since such a good correlation had been observed between the Rochester and Houlton data over the period covered by the tests, it appeared that the Rochester data might be extrapolated to cover a greater time by use of the Houlton noise readings. The same general method as outlined in Appendix A has, therefore, been applied to the Houlton loop noise data for the entire year of 1930 and the results are shown by Fig. 7. From this figure the great seasonal and diurnal variation in grade of transmission is at once apparent. It must be emphasized that

* For detail of method see Appendix A.

the per cent of errors corresponding with the average noise condition is a much more significant figure than the average per cent of errors. For example, in the Rochester tests Fig. 6 indicates that the per cent of error corresponding to average noise condition is 0.28 per cent while the observed average of the daily per cents of errors is 6.44 per cent. It is more useful to know that half of the time the copy will be better than

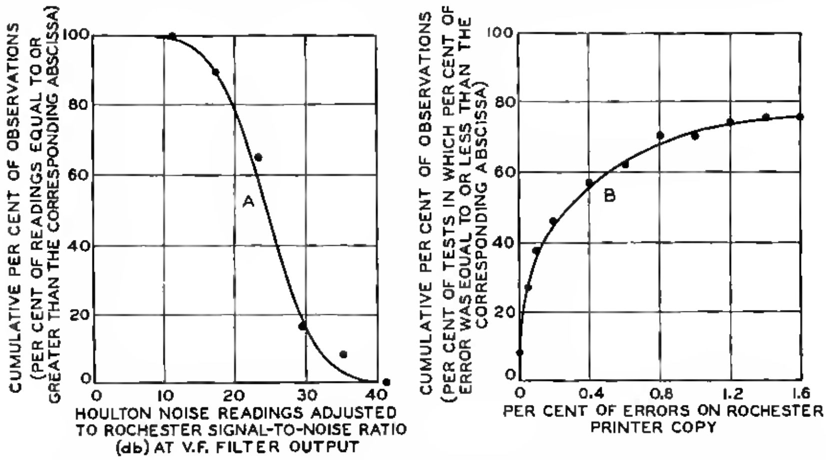

Fig. 6—Cumulative curves of signal-to-noise ratio derived from Houlton noise observations and of per cent of errors on the printer copy observed at Rochester.

0.28 per cent and half of the time worse, than to be unduly influenced by the effect on the average per cent of error of a few days in which the copy is almost all errors.

The results of the Rochester tests may be briefly summarized by giving a few figures which are based on the data obtained. A five-kilowatt station on long waves with a reasonable antenna, say 20 per cent efficient, would radiate one kilowatt. Assume that the local noise conditions are the same at the receiving station as those which have been used for the 9:00 P.M. values in Fig. 7 for Rochester, N. Y., variations. (These are obtained by applying a correction factor to the Houlton, Maine, noise observations for 1930.) Then the per cents of errors in the teletypewriter copy during the evening periods at different distances *

* As the distance varies between transmitter and receiver with the radiated power a constant, there is a variation in received signal field. If the noise is assumed to be fixed, this variation in distance will result in a variation in signal-to-noise ratio. Many of the commonly used radio transmission formulas take the form: [6]

$$E = \sqrt{P}\,\frac{300 \times 10^3}{D}\,\epsilon^{-\alpha D/\lambda^x}$$

For these calculations we have assumed $x = 1.25$ and from the field strength measurements at Rochester $\alpha = 0.023$. P is measured in kilowatts radiated, D and λ in kilometers, and E in microvolts per meter.

The various signal-to-noise ratios can then be translated into rates of error by use of Fig. 5.

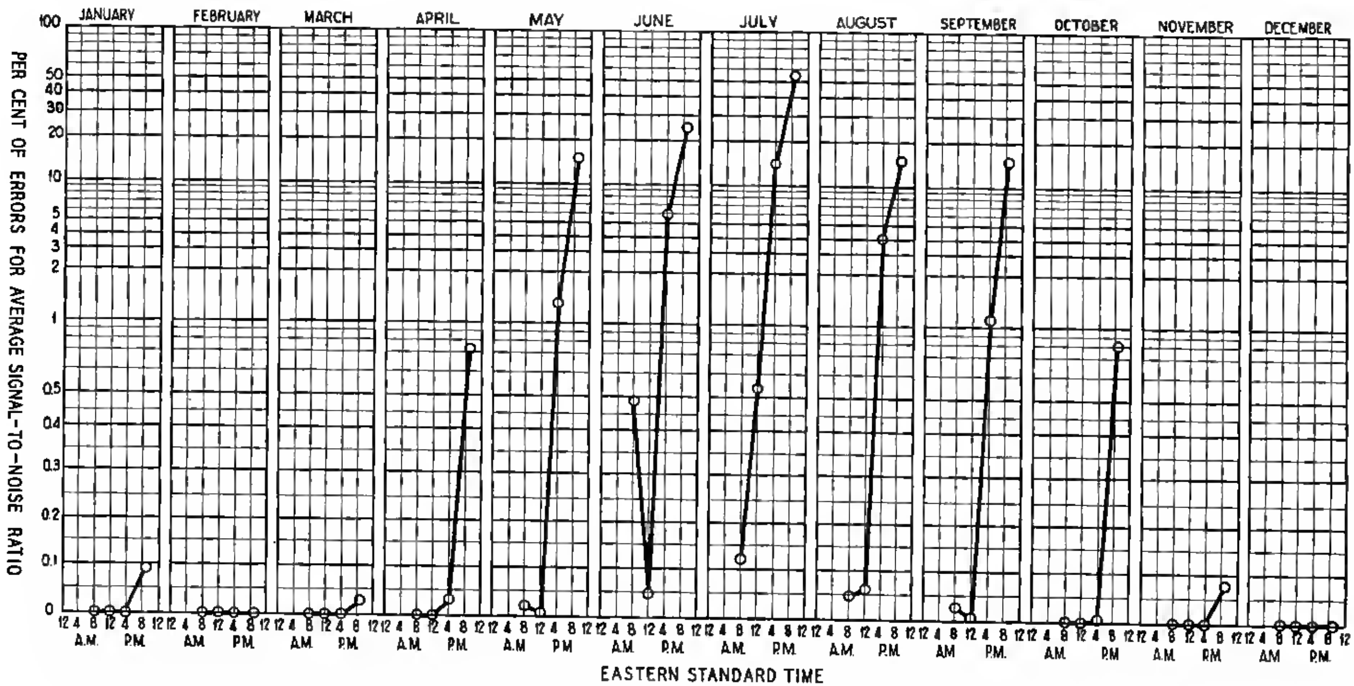

Fig. 7—Diurnal and seasonal variation of errors in printer copy to be expected over the Rocky Point-to-Rochester test radio circuit, based on Houlton noise observations in 1930.

from the transmitting station would be more than those given in the table for half of the time in each month.

TABLE II

Distance Overland from Station Radiating 1 kw at 60 kc (Statute Miles)	Errors in Printer Copy for Average Evening Noise Conditions for Each Month, Assuming Local Noise Conditions the Same as at Rochester, N. Y., and a Loop Receiving Antenna (Per Cent)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
50	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0.01	0.03	0.15	0.01	0.01	0	0	0
200	0	0	0	0.03	1.60	3.6	9.5	1.7	1.7	0.04	0	0
400	3.5	0.23	1.10	13.0	100	100	100	100	100	14.3	3.1	0.29

From these figures it is apparent that, under the conditions given, satisfactory all-year-round transmission could probably not be obtained over a radius of more than a hundred miles. To obtain the same grade of copy at a distance of 400 miles, as this assumed set-up could give at 100 miles, would require an increase in radiated power of about 25 db, making about 316 kilowatts radiated.

Development of systems and tests of the kind involved in obtaining information such as the authors have reported above have required the coöperative effort of a considerable number of engineers of the British General Post Office and of various parts of the Bell System. In solving many of the problems of telegraph signal transmission Mr. J. Herman was particularly active.

Appendix A

In deriving Curve *A* on Fig. 6 between "cumulative per cent of observations" and "Rochester signal-to-noise ratio at the voice-frequency filter output" from the Houlton noise data, the following facts were assembled and coördinated. In the first place, it was determined from the analysis of a large number of observations of loop noise at Houlton, that the magnitude of the noise is random and that its distribution obeys the Normal Law of Probability frequently used in engineering studies, provided the values of noise are in each case expressed as the number of decibels the "warbler" noise is above one microvolt per meter. Since each observation requires about the same time to complete and the observations are made at the same fixed times each day, the process really becomes one of sampling and the "per cent of observations" is equivalent to the "per cent of time" for the period covered by the tests. Then if, as in the Rochester tests, the radio signal strength is substantially constant, the signal-to-noise ratio (expressed

in db) becomes simply a constant minus the noise value (also expressed in db); and finally to get the signal-to-noise ratio at the voice-frequency filter output, a constant correction factor must be subtracted to take care of the band width, the difference in the methods used to measure noise and the difference in the absolute value of the noise observed at the two stations. Of course, if the Houlton loop noise is equal to or less than a given value for say 90 per cent of the time, the signal-to-noise ratio at the voice-frequency filter output derived from the Houlton noise will be equal to or less than its value for 10 per cent of the time.

Curve *B* of Fig. 6 is obtained directly from the observed errors on each test at Rochester and indicates in what per cent of the tests the per cent of errors observed was equal to or less than the value of "per cent of errors" given by the corresponding abscissa.

To combine the two curves of Fig. 6 it must be assumed that for each value of signal-to-noise ratio at the voice-frequency filter output there can be but one value for the observed per cent of errors, i.e., the variation in the per cent of errors depends only upon the signal-to-noise ratio received. If this is true, it is evident that a certain signal-to-noise ratio occurring a definite per cent of the time will always correspond to the per cent of errors which occurs the same per cent of the time. Hence, from the cumulative curves of Fig. 6 a curve relating signal-to-noise ratio with per cent of errors can be derived which is the same as Fig. 5. To do this a certain signal-to-noise ratio for which the corresponding per cent of errors on the Rochester printer copy is desired is selected. Curve *A* of Fig. 6 shows that this or some larger value of signal-to-noise ratio occurs *P* per cent of the time, but *P* per cent of the time, according to Curve *B* of Fig. 6, the per cent of errors on the Rochester printer copy was equal to or less than *E*. It is apparent, therefore, that *E* must be the value desired.

Assuming some constant received field strength at Rochester it is possible by this method to convert any individual Houlton loop noise observation into the corresponding per cent of errors on the Rochester teletypewriter copy.

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